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A BRIEF OVERVIEW OF THE HYDROGEOLOGY OF THE MAJOR AQUIFERS AND AQUIFER SYSTEMS IN WYOMING

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INTRODUCTION

Ground-water withdrawals provide drinking water to more than 50 % of the population in the State of Wyoming. Most public-supply systems in the State use ground water and about 90 % of the rural domestic use is supplied by ground water. In 1980, approximately 606,500 acre feet of ground water was withdrawn for municipal, domestic irrigation and industrial use. About 69 % of this, or 418,500 acre feet, was used for irrigation. Another 24 %, or 145,000 acre feet, was used for industrial purposes mainly for development of energy and mineral resources. Approximately 50 % of the ground water used in the State is withdrawn from the High Plains aquifer system; about 30% is withdrawn from valley-fill sediments and about 20% is withdrawn from sedimentary rocks in the structural basins (R.M. Stockdale, Wyoming SEO, personal communication, 1993).

PHYSIOGRAPHY AND GEOLOGY

Wyoming is a diverse state in terms of physiography and geology. The surface terrain is characterized by the massive, rugged glaciated mountains of the southern and middle Rocky Mountains, large sedimentary basins and the western reaches of the Great Plains. Four physiographic provinces are recognized in the state including the Great Plains, Wyoming Basin, Southern Rocky Mountains and Middle Rocky Mountain provinces (Fenneman, 1931). The diverse geologic features and land forms result in significant differences in the occurrence and availability of ground water in the state.

The mountains are formed of metamorphic and igneous rocks of Precambrian age. Tertiary and Quaternary volcanic rocks are exposed in northwest Wyoming. The mountains are characterized by complex geologic structures, with abundant folds and faults. Large thicknesses of sedimentary rocks overlie the Precambrian complexes and generally appear as asymmetrical synclinal basins interspersed between mountain ranges. These basins contain up to 33,000 feet of sedimentary rocks from Cambrian to Tertiary in age. Sedimentary formations generally are steeply dipping along

the margins of the basins and flatten out a short distance from the mountain front. Locally the relief is significant between the mountain ranges and the adjacent sedimentary basins.

A variety of unconsolidated surficial deposits occur within the mountain valleys and basin floors. Glacio-fluvial and Recent alluvial deposits occur in modern stream valleys. In the southeast part of the State semi-consolidated Miocene deposits represent a remnant of a large alluvial plain built by streams flowing eastward from the Rocky Mountains.

HYDROGEOLOGY

Five ground-water regions occur within the State of Wyoming; the Western Mountain ranges region, the Colorado Plateau and Wyoming Basin region, the High Plains region, the NonGlaciated Central region and the Alluvial Valleys region. Within each region the occurrence and availability of ground water is similar with respect to the geohydrology, the nature of the porosity of the primary aquifer(s), the solubility characteristics of the rock matrix of the primary aquifer(s), the hydraulic characteristics of the primary aquifer(s) and the nature and location of recharge and discharge areas (Heath, 1984). The nature and extent of the primary aquifers and their hydrologic relationship to other parts of the ground-water flow system(s) are the main criteria for delineating ground-water regions. Ground-water regions are also related to physiographic regions because the occurrence and availability of ground water depend on composition, arrangement and structure of rock units (Heath, 1982).

Virtually all of the stratigraphic units in Wyoming basins play a hydrologic role either as a major aquifer, a minor aquifer, or an aquitard. Over 100 aquifers and aquifer systems have been identified within the State, however many are limited in extent and yield only small amounts of water to wells. For purposes of this discussion, the geologic units that occur in the State are divided into eight principal aquifer systems: unconsolidated valley-fill deposits, principally found along or adjacent to major drainages; semi-consolidated to locally consolidated sedimentary rocks in the High Plains aquifer system; and consolidated sedimentary rocks (including carbonates) found within or flanking six major structural basins: the Powder River Basin, the Bighorn Basin, the Wind River Basin, the Green River Basin, the Washakie / Great Divide Basin and the Denver/Julesburg Basin. (Slide) (Figure).

Ground-water quality varies significantly within and between ground-water regions and aquifer systems and reflects both natural and human activities. Ground water contained in most aquifer systems in the State is suitable for a variety of

beneficial uses. Large concentrations of dissolved solids and naturally occurring concentrations of fluoride, selenium, iron, manganese and radionuclides are common locally. High nitrate concentrations are locally common, particularly in water from alluvial and other shallow aquifers, and are the result of contaminants issuing from septic-tank leach fields, applied fertilizers and feedlots.

VALLEY-FILL DEPOSITS

The valley-fill sediments that occur within the floodplains and terraces of the major modern day rivers and streams in Wyoming are within the Alluvial Valleys ground-water region as described by Heath (1984) who also has established three criteria that are used to differentiate alluvial valleys from other valleys. These are as follows:

1. The valleys contain sand and gravel deposits thick enough to supply water to wells at moderate to large rates.
2. The sand and gravel deposits are in hydraulic contact with a perennial stream which serves as a source of recharge and whose flow commonly exceeds the demand.
3. The sand and gravel deposits occur in a clearly defined band (or channel) that normally does not extend beyond the floodplain and adjacent terraces (the width of the deposits is small compared with its length).

The valley-fill aquifers of Wyoming fit these criteria and consist mostly of alluvial and glacio-fluvial deposits that occur as terrace and floodplain deposits along the major rivers in the state. The most significant deposits are located along the North Platte, the upper Snake, the Bear, and the Greybull Rivers. At least five additional rivers systems have been classified as alluvial aquifers but are mostly of local concern.

The North Platte heads in northern Colorado, flows northward into Wyoming to the general area of Casper where it loops southeastward and exits the state into Nebraska near Torrington. It is the most significant valley-fill aquifer in the state in terms of size, water storage and availability for agricultural, municipal and industrial uses. It is comprised in large part of unconsolidated coarse grained glaciofluvial sediments.

The Snake River heads in Yellowstone National Park and flows southward through Grand Teton National Park and then swings westward into Idaho. The upper Snake River valley contains several hundred feet of glaciofluvial sediments within the floodplain. South of Jackson, Wyoming, the valley fill is comprised of gravel and coarse sand and supplies large quantities

of water to wells.

The Bear River heads in the Uinta Mountains of Utah, flows northward through Utah and the southwest corner of Wyoming and then into Idaho near Cokeville. The Greybull rises in the Absaroka Range, trends northeastward and enters the Bighorn River near Greybull.

According to Zimmerman (1984) the valley-fill sediments range in thickness from 10 to 100 feet but much greater thicknesses occur in the Bear and Snake River valleys. These greater thicknesses have been attributed to recurrent structural deformation and concurrent deposition. Well yields commonly range from 50 to 100 gpm and locally exceed 3,000 gpm. Transmissivity and hydraulic conductivity are generally high particularly where glacio-fluvial deposition has occurred. Reported transmissivities are generally from 1000 to 65000 gpd/ft except where there is significant glaciofluvial deposition where transmissivities can exceed 750,000 gpd/ft.

Water quality in the valley-fill sediments is generally suitable for most purposes. Concentrations of total dissolved solids typically range from 200 to 1200 mg/l and average about 500 mg/l. Prior to irrigation, many Quaternary terraces were dry or had relatively saturated thicknesses. With the advent of irrigation practices, saturated thicknesses and total dissolved solids (TDS) concentrations have increased. The additional water increased the leaching of soluble minerals within the terrace and floodplain deposits and increased the TDS concentrations downstream. Hardness typically ranges from 100 to 1000 mg/l as calcium carbonate. In some agricultural areas nitrate concentrations in the valley-fill deposits exceed the Federal maximum contaminant level of 10 mg/l. Outside of the agricultural areas nitrate concentrations are typically less than 1 mg/l.

HIGH PLAINS AQUIFER SYSTEM

The High Plains aquifer system underlies portions of eight states (Figure) (SLIDE). In Wyoming it occurs only in the southeast quarter of the state where it is bounded on the west by the Laramie Mountains.

In Wyoming, the High Plains aquifer is comprised of the upper Miocene Ogallala Formation and the underlying lower Miocene Arikaree Formation. Locally, the underlying Oligocene Brule Formation is considered a part of the Tertiary High Plains aquifer where it contains sandstones or secondary permeability.

The Ogallala is generally semi-consolidated and consists of poorly sorted silt, sand and gravel with minor clay, which becomes coarser and less cemented in the lower parts of the formation. The Arikaree rocks are predominantly massive, fine-grained sandstone with localized beds of other fine grained to amorphous sediments. The aquifer can exceed 1,000 feet in thickness in some places.

The High Plains aquifer system is the most developed aquifer system in the State. Approximately 50% of the ground-water developed in the State is withdrawn from the High Plains (R. M. stockdale, personal communication, 1993) Ground water is developed for irrigation, municipal and industrial water needs. Ogallala production is mainly in Laramie County, whereas, the Arikaree is present in the remainder of the High Plains region.

Well yields of several hundred gallons per minute are common from the High Plains aquifer system with yields of 1000 gpm being common locally. Transmissivity values range from 1,600-700,000 gpd/ft for the Ogallala and from 110-77,000 gpd/ft for the Arikaree. Hydraulic conductivity ranges from 160-4000 gpd/ft² for the Ogallala and from 1.3 to 375 gpd/ft² for the Arikaree. Both formations have essentially similar specific capacity figures - 0,2 to 230 gpm/ft. (Libra, 1981, p.39).

Natural water quality in the High plains aquifer is typically very good and suitable for all beneficial uses. However the aquifer is very sensitive to contamination from overlying land use. Concentrations of total dissolved solids are typically less than 500 mg/l. Ground water from the high plains is typically moderately hard to hard with concentrations averaging less than 200 mg/l as calcium carbonate. Locally nitrate concentrations exceed 10 mg/l but are typically less than 2 mg/l.

STRUCTURAL BASINS

The asymmetrical structural, sedimentary basins of Wyoming are somewhat similar to one another with respect to hydrogeology. The six major basins discussed in this paper contain from 12,000 feet (Denver-Julesburg basin) to 43,000 feet (Green River basin) of Phanerozoic sedimentary rocks. Mesozoic rocks (mainly Cretaceous) typically comprise the greatest thickness within the basins (11,000 to 15,000 ft), the Cenozoic section is less thick (8000 to 9000 ft) and the Paleozoic rocks are the least thick section (3000 to 4000 ft) (SLIDE)

Within these basins, various workers have delineated three major hydrologic units. Each hydrologic unit is comprised of a

group of formations which function as a single regional hydrologic unit. The formations are stratigraphically adjacent units which have regional areal extent , similar hydraulic properties and similar recharge/discharge characteristics. a Hydrologic units can function as regional aquifer systems or regional aquitards. Regional aquifer systems are comprised of stratigraphically adjacent formations which consist of permeable lithologies - sandstones, limestones, siltstones or sedimentary formations with significant secondary fracturing. Regional aquitards consist of groups of formations which consist primarily of shale and siltstone.

The formations which comprise a regional aquifer system are hydraulically connected to one another over large parts of their occurrence. Ground water can occur under both confined and unconfined conditions within a regional aquifer system. Ground water flows from one formation to another under a variety of hydrologic conditions and withdrawal of ground water from one formation affects the pressure head in adjacent formations. Formations which comprise aquifers can behave locally as individual aquifers with a minimal degree of hydraulic connection.

Regional aquitards are comprised of thick sections of shales and siltstones which retard the flow of ground water and form boundaries for the regional aquifer systems. If thick enough these low permeability rocks will function as an aquitard. If they are not thick enough they will typically function as leaky confining units.

Contained within these regional aquifer systems and aquitards are local aquifers which are comprised of permeable formations of limited areal extent or a permeable member of a formation which is otherwise a low permeability unit. These aquifers tend to be discontinuous and often interbedded with low permeability sedimentary rocks.

For the six major sedimentary basins discussed in this paper the upper hydrologic unit is comprised of Upper Cretaceous and Tertiary clastic rocks. These rocks function as a regional aquifer system. Below this a thick section of Cretaceous marine rocks comprise a regional aquitard. This section of rocks separates the upper regional aquifer system from the underlying Paleozoic aquifer system which is comprised of primarily of limestones and sandstones of Cambrian to Pennsylvanian in age and is considered to be a separate hydrologic unit..

Upper Hydrologic Unit

The base of the upper hydrologic unit is typically formed by the Lance and Fox Hills Formations of late Cretaceous age. The Fox Hills Formation is a regressive sandstone that occurs throughout Wyoming. The overlying Lance Formation is a siltstone/sandstone which was deposited in a low energy coastal environment. The Paleocene Fort Union Formation overlies the Lance Formation in all of the basins except the Denver-Julesburg where the Lance is overlain by the Oligocene White River Group. The Fort Union Formation is overlain by the Wasatch Formation in the Green River, great Divide and Powder River basins. The Fort Union and Wasatch Formations are comprised of interbedded sandstones, siltstones and coals. In the Wind River basin the Fort Union is overlain by the Wind River Formation which is a stratigraphic equivalent to the Wasatch Formation.

The upper Tertiary Ogallala and Arikaree Formations form the top of the upper hydrologic unit in the Denver-Julesburg, Powder River and Wind River basins. In the Green River and Great Divide basins the top of the upper hydrologic unit is formed by the upper Tertiary Browns Park, North Park and South Pass Formations. The upper Tertiary formations are comprised of semi-consolidated to consolidated coarse grained clastic rocks including conglomerates.

Locally the upper hydrologic unit may be divided into three aquifer systems: the Lance-Fox Hills, the Wasatch-Fort Union and the Ogallala-Arikaree or North Park-Browns Park-South Pass aquifer systems. These aquifer systems may be separated by leaky confining units of various thickness and extent.

Reported well yields from the formations which comprise the upper hydrologic unit range from 2 to 3000 gpm. Typically well yields are less than 200 gpm. Reported transmissivities range from 500 to 10,000 gpd/ft.

The natural quality of ground water contained in formations of the upper hydrologic unit varies considerably. Concentrations of total dissolved solids can vary from a few hundred mg/l to a few thousand mg/l, typically increasing away from recharge areas. The total dissolved solids concentration and the concentrations of specific ions is affected by the formations encountered along the flow path. Local lithologic variation greatly controls anion composition. Bicarbonate and sulfate tend to be the dominant anions except for deeper ground waters. Adsorption and exchange processes control cation composition. Sodium and calcium are more common than magnesium.

Regional aquitard system

In all six sedimentary basins the upper hydrologic unit is underlain by a thick sequence of lower and upper Cretaceous marine shales and associated minor limestones. The shales were deposited in the large intracontinental sea. The shales are typically 4000 to 6000 feet thick in the centers of the basins. The thick marine sections function as a regional aquitard. The principle shale formation in this aquitard is upper Cretaceous in age and is called the Pierre Shale in the Denver-Julesburg basin and the Powder River Basin. It is called the Cody Shale in the Bighorn and Wind River Basins and it is called the Lewis Shale in the Green River basin and the Great Divide basin. This principle shale is typically underlain by lower Cretaceous shales of lesser thickness. Except for the basin margins, this great thickness of low permeability rocks effectively precludes hydraulic connection between the overlying regional aquifer system and rocks underlying the regional aquitard.

In the Powder River basin the lower Cretaceous shales are underlain by sandstones of the Inyan Kara Group - the Fall River Formation and the Lakota Formation are the principle sands. These rocks comprise the Dakota aquifer system.

In all six basins the Jurassic, Triassic, and Permian rocks comprise a series of local aquifers and leaky confining units or aquitards. These rocks consist primarily of siltstones and evaporites.

Lower hydrologic unit

A lower hydrologic unit has been identified in all six basins. This hydrologic unit is comprised of a sequence of sandstones and carbonates of Cambrian to Pennsylvanian in age. The bottom of the hydrologic unit is a Cambrian sandstone called the Flathead Sandstone in all of the basins except the eastern half of the Powder River basin where it is called the Deadwood Sandstone. This sandstone is typically overlain by a thick carbonate section of Ordovician and Mississippian age. Except for the Denver-Julesburg basin the Ordovician Bighorn Dolomite and the Mississippian Madison Formation comprise the greatest thickness of carbonates. In the Denver-Julesburg basin this section of rocks is represented by the very thin Guernsey limestone. A thick section of lower Permian and Pennsylvanian sandstones overlies the carbonate rocks in all six basins. The Permian-Pennsylvanian Tensleep Sandstone forms the top of this lower hydrologic unit in all but the Denver basin where the Hartville and Casper Formations form the top.

This lower formations which comprise the hydrologic unit have a combined thickness of 1000-3000 feet. Reported transmissivities typically range from 1000 to 60,000 gpd/ft. Significant karst has developed in the upper part of the Madison

limestone. Well developed in the karst areas have reported yields of 2000 gpm. Though the formations that comprise this lower hydrologic unit are productive aquifers, they have not been greatly developed due to great depths.

Concentrations of dissolved solids are typically less than 500 mg/l. Ground water in the carbonates is typically a calcium carbonate type near the basin margins. basinward the water is typically a calcium sulfate. Tensleep ground waters and Madison ground waters are typically similar in type.

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